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Author(s):
Moss, Calvin Elroy
Baruzzini, Matthew Louis
Chichester, David L.
Determan, John C.
Hutchinson, Jesson D.
Myers, William L.
Nelson, Mark Andrew
Sorensen, Eric Byron

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Development of a Portable Active Interrogation System for Characterizing Special Nuclear Material

C. E. Moss[1, a)], M. L. Baruzzini[1, b)], D. L. Chichester[2, c)], J. C. Determan[3, d)], J. D. Hutchinson[1, e)], W. L. Myers[1, f)], M. A. Nelson[1, g)], and E. B. Sorensen[1, h)]

[1]*NEN-2: Advanced Nuclear Technology, Los Alamos National Laboratory, P.O. Box 1663, Los Alamos, NM 87545*
[2] *Idaho National Laboratory, Idaho Falls, ID 83415*
[3]*NEN-5: Systems Design and Analysis, Los Alamos National Laboratory, P.O. Box 1663, Los Alamos, NM 87545*

[a)]Corresponding author: cmoss@lanl.gov
[b)]mbaruzzini@lanl.gov
[c)]david.chichester@inl.gov
[d)]determan@lanl.gov
[e)]jesson@lanl.gov
[f)]bmyers@lanl.gov
[g)]manelson@lanl.gov
[h)]esorensen@lanl.gov

Abstract. Detection, identification, and characterization of shielded Special Nuclear Material (SNM), and especially of Highly Enriched Uranium (HEU), often require active interrogation. Active interrogation with neutrons or high energy photons induces fission and thus causes the emission of characteristic gamma and neutron radiation. The detection of the emitted radiation with simple detector systems often only indicates the presence of SNM. Analysis of the correlations of the neutron emissions can provide characteristics of a material, such as multiplication and mass. Such analyses are used in well counters for characterizing SNM. Our system consists of a portable pulsed neutron generator and a portable list-mode neutron detection system. The neutron correlations between the intense interrogating pulses from the neutron generator are analyzed to determine characteristics of the SNM. After the last interrogating pulse, the die away is analyzed to identify the type of SNM. We report data from a variety of SNM objects and present preliminary analysis results.

INTRODUCTION

There is a need to detect and characterize special nuclear material (SNM) is many different situations. Simple passive detector systems, such as gamma-ray or neutron detectors, often can only indicate the present of radioactive material. Analysis of the spectra, for example, with a RIID (Radiation Isotope Identification Device), may be able to identify the material. The detected material can be further characterized by analysis of the neutron correlations to provide, for example, the mass and multiplication.

The detection, identification, and characterization of shielded SNM, and especially of HEU (Highly Enriched Uranium), often require active interrogation. HEU only emits a weak 186-keV gamma ray, which is easily shielded. Active interrogation with photons or neutrons is required to cause fission and thus produce characteristic neutrons and gamma rays that can be detected. The Domestic Nuclear Detection Office (DNDO) has performed tests of some large active interrogation systems applicable to vans, trucks, and railcars [1]. In this report we describe a portable active interrogation system and present some results with a focus on analysis of neutron correlations and beta-delayed neutron die away.

SETUPS AND DATA MEASUREMENTS

Figure 1 shows a typical active interrogation setup with preferred dimensions. The system consists of a small commercial neutron generator, two NoMAD list-mode neutron detector systems containing 15 ^{3}He tubes in polyethylene moderator with electronics to minimize pileup, and SNAP (Shielded Neutron Assay Probe) for accurate measurement of the neutron flux. We used a Thermo Fisher B211 neutron generator for measurements at Los Alamos National Laboratory (LANL) and a Thermo Fisher MP320 for measurement at Idaho National Laboratory (INL). The B211 is a repackaged version of the Thermo Fisher P211. The NoMAD detectors were designed at LANL and use a 100-ns clock for time tagging the pulses. These detectors are not commercially available. The SNAP detector, also designed at LANL, contains one ^{3}He tube and is shielded on the back, sides, top, and bottom by polyethylene. It has a removable one-inch thick polyethylene shield on the front. It has been calibrated at many distances, with and without the front shield, and provides an accurate measurement of the neutron source strength.

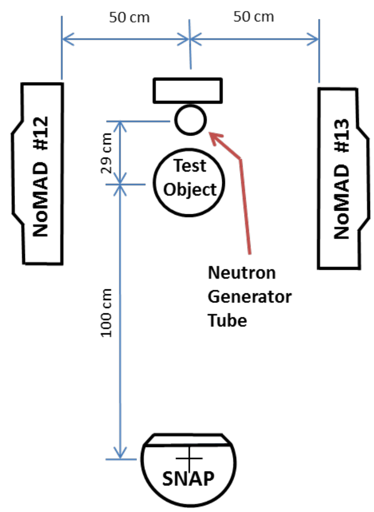

FIGURE 1. Typical active interrogation setup with preferred dimensions.

LANL Setup

Figure 2 shows a setup with depleted uranium shells at LANL in a shielded room. The electronics for the neutron generator (NG) are outside the shielded room and are connected to the NG via cables. Note that the system here is elevated above the floor. The height of the system components above the floor and/or the distances to any nearby neutron reflectors, such as walls, must be included in the neutron correlation analysis because the system is calibrated for various distances. For a measurement in the field, setups such as those in Figures 1 and 2 may not be possible. For example, only one side of the test object may be accessible, and all of the system components may need to be placed on one side of the object. Also, the relative distances might need to be different from those shown in Figure 1. The details needed to be recorded for analysis.

Only data between the interrogating pulses from the neutron generator are analyzed for neutron correlations because the rate of uncorrelated neutrons during the pulses is too high. The data were vetoed off during the generator pulse to reduce the data being stored in memory. The beta-delayed neutrons provide interrogation between generator pulses. The B211 generator at LANL was operated at 50 Hz, which provided 20 ms between the 10 µs generator pulses as shown in Figure 3. The big peaks are the die away at the end of the generator pulses. The data of interest are the very small peaks between the generator peaks, which are due to delayed neutrons and fissions induced by these delayed neutrons.

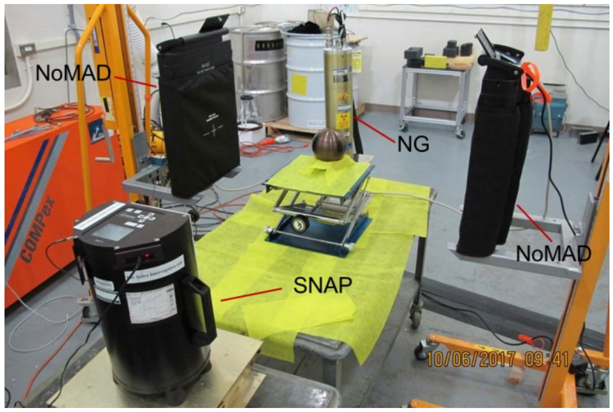

FIGURE 2. Setup at LANL with 32 kg depleted uranium shells containing 0.21% ^{235}U and 0.75% titanium.

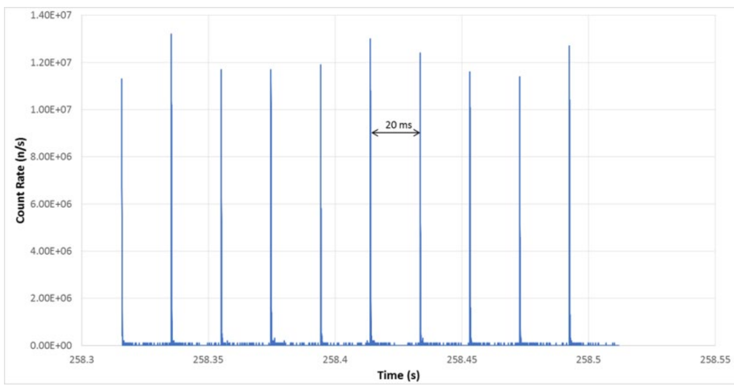

Figure 3. Pulses from the B211 neutron generator at LANL.

As shown in Figure 4, the data were taken in three time regions: before the NG was turned on, when the NG was on, and after the NG was turned off. The region before the NG was turned on provided background; the region after the NG was turned off provided data on the beta-delayed neutron die away.

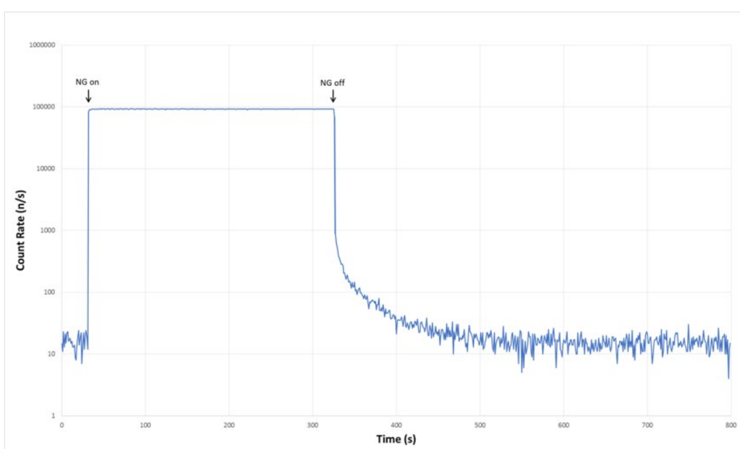

Figure 4. Neutron count rate from the depleted uranium shells at LANL. The individual generator pulses are not seen because of the reduced time resolution.

INL Setup

Figure 5 shows a setup with the MARVEL HEU disks on the concrete floor in the shielded Zero Power Physics Reactor (ZPPR) facility at INL. The NG was mounted on the electronics, but they were controlled with a computer outside the shielded area.

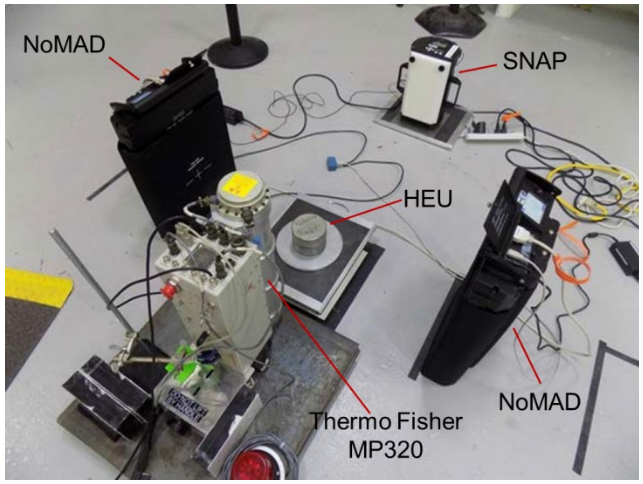

Figure 5. Setup with 14.8 kg of MARVEL HEU disks at INL.

The MP320 generator was operated at 300 Hz, which only allowed 3.3 ms between pulses as shown in Figure 6. Data acquisition was vetoed during the 333 μs NG pulse. The data were again taken in three time regions, as shown in Figure 7. Note the higher count rate with HEU in the die-away region compared to the die-away region with LEU in Figure 4.

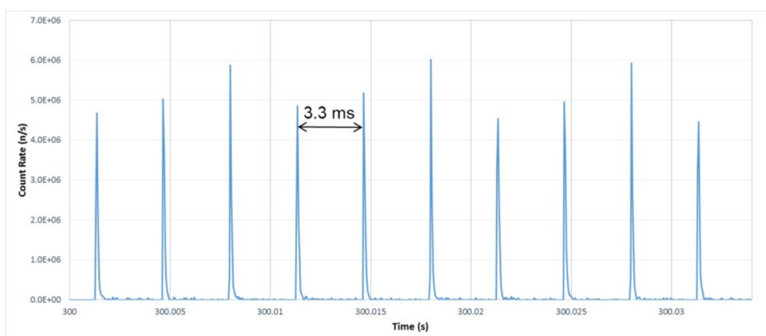

Figure 6. Pulses from the MP320 neutron generator.

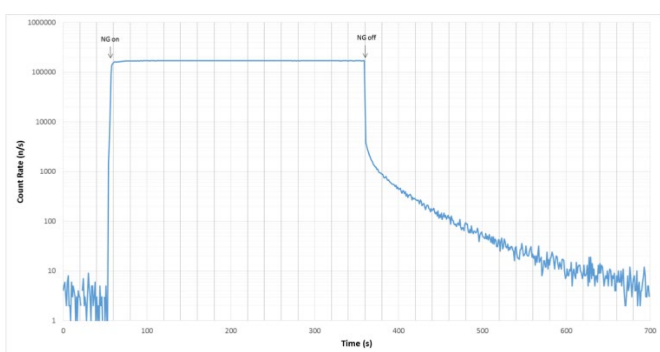

Figure 7. Neutron count rate from the MARVEL HEU disks.

Other objects measured included HEU oxide samples, 32 LEU fuel pins, 32 HEU fuel pins, and an HEU sphere. A total of 89 configurations were measured with various numbers of objects, shielding, and numbers of objects.

ANALYSIS

Neutron Correlations

To analyze the neutron correlations we used the LANL code Momentum, which was originally written to analyze passive, i.e. not active, neutron data [2]. A separate LANL code, FeynView, was written to select the data between the generator pulses and prepare Feynman histograms for input to Momentum. Inputs to FeynView include the lower and upper time limits between generator pulses to search for events, the minimum Feynman gate width, the gate width step, and the total number of gates. Figure 8 shows a Momentum screen after the Feynman histograms are entered in Momentum. The Feynman histogram shown is the one with the midpoint gate width. The Feynman histogram is higher than the Poisson distribution (orange curve) because of neutron correlations caused by fissions.

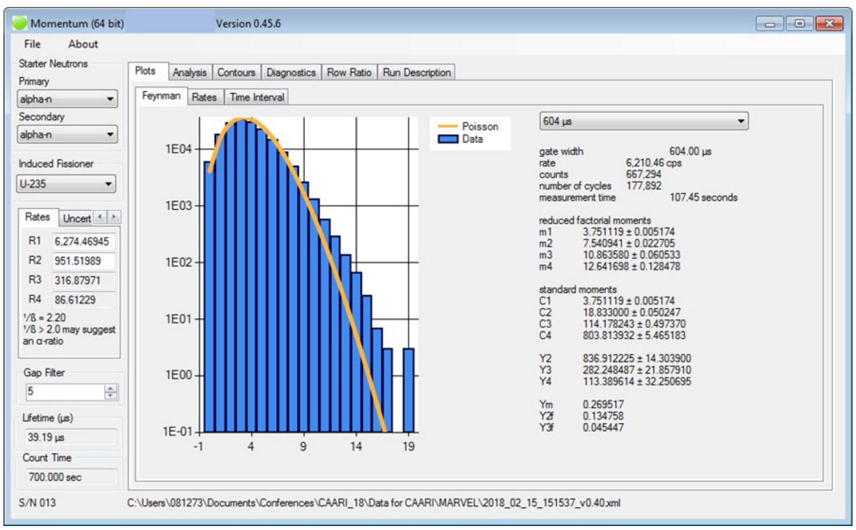

Figure 8. Momentum screen shoot after the Feynman histograms from FeynView are entered.

Momentum is a powerful program for analyzing neutron data. It uses the Feynman histograms together with other parameters, such as the efficiency, neutron source strength, and transmission through any surrounding shielding, to calculate other parameters, such as multiplication and mass. The Feynman histograms and the various parameters are related by a set of several equations first described in detail by Hage and Cifarelli [3,4]. If some parameters are known, the equations can be used to calculate unknown parameters. The most common problem is to calculate the multiplication and mass when the other parameters are known.

Table 1 shows a comparison of the leakage multiplication calculated by Momentum for the MARVEL HEU disks with the k-code simulation [5]. The simulation result might be low because reflections from the neutron generator, support platform, floor, and NoMADS were not included.

Table 1. Multiplication Results for MARVEL HEU Disks

Type of Analysis	Leakage Multiplication
Momentum Code	3.44
k-code Simulation	3.30

Die Away

The neutron response in the die-away region after the generator is turned off in Figures 4 and 7 is driven by a time-dependent decreasing population of delayed neutrons precursors. The neutron response appears to be a sum of decaying exponentials that are functions of the delayed neutron precursor population. This population is a function of the target object enrichment. An earlier more detailed study showed that the enrichment could be determined with an uncertainty of 2-6% [6]. This can be useful when gamma spectroscopy cannot provide an enrichment because of shielding. Figure 9 shows a comparison of the die-away data for the MARVEL HEU disks and the DU shells. More calibrations and fitting of the curves for samples with different enrichments but similar masses and shapes would be required to determine enrichments for the present objects.

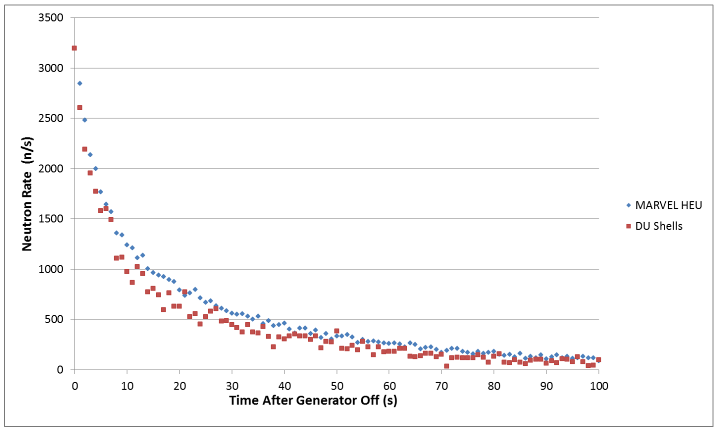

Figure 9. Comparison of die aways for HEU and DU.

CONCLUSIONS

The current commercial hardware is suitable for a portable system. However, smaller, lighter weight equipment is always desired provided it can provide the at least 10^7 n/s and sufficient time between pulses to measure neutron correlations. The FeynView code provides Feynman histograms for input to the Momentum neutron correlation code. The Momentum code provides results, such as multiplication and mass. For passive measurements, the Momentum code provides results for a few kilogram SNM sample based on an analysis of a 5-minute measurement, and we expect similar results for active measurements. It has been shown that the die-away region can provide the enrichment of an object, but more calibration and analysis is required to make this a standard technique.

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